Characteristics of a Cigar Antenna

S. A. Brunstein and R. F. Thomas

Telecommunications Division

Dual-frequency propagation experiments will be performed using the Deep Space Network 64-m antennas and the *Mariner* Venus–Mercury 1973 and *Viking* orbiter 1975 spacecraft. For such experiments, the 64-m antennas must be capable of receiving and transmitting at S-band and simultaneously receiving at X-band. One possible configuration involves placing an X-band feed inside the S-band feed horn.

A cigar (metallic-disc-on-rod) antenna was investigated for this application because this type of antenna is physically thin and would have minimal effect on the radiation from the S-band feed horn. A cigar antenna design obtained using new phase velocity data is described in this article. The new phase velocity measurements were required when it was found that the available published data for disc-on-rod structures were in error. The new measurements and the experimental results obtained with the resulting design are also described.

Introduction

Dual-frequency propagation experiments will be performed using the Deep Space Network 64-m antennas and the *Mariner* Venus–Mercury 1973 and *Viking* orbiter 1975 spacecraft (Reference 1). For these experiments, the 64-m antennas must be capable of receiving and transmitting at S-band and simultaneously receiving at X-band.

Several configurations are being investigated to implement this capability. One involves a coaxial feed in which an X-band radiator is placed inside the S-band feed horn on the centerline. The obvious requirement is that the X-band device must be diametrically small to avoid distortion of the fields in the S-band horn. The X-band feed must also have a radiation pattern that is very similar to that of the S-band feed (Reference 2) in order to achieve essentially identical aperture efficiencies at both frequencies.

Investigation of antenna types that could be used led to the class of long, thin, endfire antennas typified by the polyrod (dielectric) antenna (Reference 3, pp. 16–23). These antennas are slow-wave structures that achieve their gain by length rather than by aperture size. Scale-model experiments showed that this type of antenna of the approximate required size could be placed in the S-band feed horn with negligible effect on the radiation pattern. Specifically, it was decided to investigate a relatively little known form known as the cigar or disc-on-rod antenna. This antenna, essentially a metallic analogue to the polyrod antenna, was chosen because of concern for the effect on S-band system noise temperature if a dielectric rod was introduced into the S-band horn. A cigar antenna is shown in Figure 1.

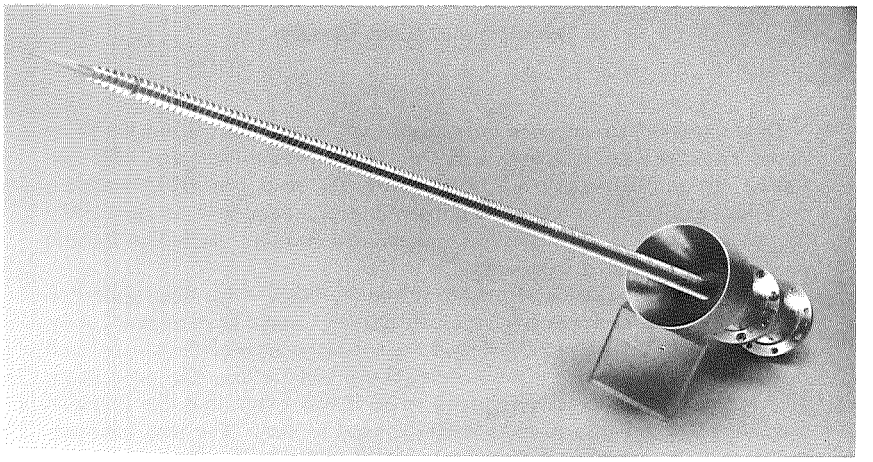

Figure 1. Cigar antenna

General design criteria for lengths, phase velocities, etc., required to achieve a given result with a slow-wave endfire antenna are thoroughly discussed by Jasik in Reference 3. Jasik also discusses phase velocity as a function of physical dimensions of disc-on-rod structures, based on the work of Simon and Weill (Reference 4). Based on the material in Reference 3, investigation of a cigar antenna was begun.

However, the initial results achieved with the cigar antenna did not meet expectations. Since the general phase velocity design criteria had been amply proven in polyrod antennas, the phase velocity data for the disc-on-rod structures became suspect; thus, an experimental program was undertaken to obtain new phase velocity measurements for these structures.

Phase Velocity Measurements

Phase velocity measurements were performed by three different techniques over a frequency range of 7–10 GHz. In all cases, the disc-on-rod

structure was fed from a circular X-band waveguide, excited by the linearly polarized TE_{11} mode. The inside diameter of the waveguide was 3.477 cm. The first disc of the disc-on-rod structure was located in the waveguide aperture. No discs were inside the waveguide, but the support rod extended several centimeters into the waveguide, and the disc-on-rod structure was supported by two thin Micarta discs inside the waveguide. The disc-on-rod structures had disc diameters ranging from 1.397 to 2.159 cm, with center-to-center spacings of 0.635, 0.953, and 1.270 cm. Two support rod diameters were used: 0.635 and 0.953 cm. The discs had a thickness of 0.0762 cm in all cases. Although difficulty was experienced with spatial harmonics throughout the measurements, the results were sufficiently conclusive to demonstrate that the data of Simon and Weill are substantially in error.

Measurements were first performed by moving a large metal plate with a hole for the cigar structure along the cigar and measuring the relative phase of the reflected energy with a Hewlett–Packard network analyzer to establish the wavelength on the cigar. The results of this measurement appeared to disprove Simon and Weill, so further investigation was felt to be in order.

The next technique used a small probe to measure the relative phase along a cigar structure that was terminated into free space with a taper; the last technique was identical, except that the cigar was terminated into a block of microwave absorber.

All of the measurement techniques suffered from the usual problem whereby the methods upset the fields sufficiently to affect the measurements. The difficulty was especially acute when the velocities on the structure approached the free-space velocity. Nevertheless, all three sets of measurements showed substantial agreement, and the results were quite different from those of Simon and Weill. The belief in the correctness of the measurements is substantiated by the fact that the cigar antenna designed from these data worked precisely as anticipated.

The results of the measurements are shown in Figure 2, along with the curves of Simon and Weill. The parameter limits for which the results are considered valid are shown on the figure. During the course of the measurements, it was found that the phase velocities were reasonably well-behaved until either the spacing of the discs or the diameter of the support rod approached 0.25 wavelengths. At values greater than about 0.21 wavelengths, the data became quite erratic, and it appears that the phase velocity is not a smooth function of physical dimensions above this value. Values smaller than 0.15 wavelengths were not investigated, nor were the effects of disc thickness.

The data shown by the points on Figure 2 did not justify more than a single phase velocity curve. It appears that the disc spacing does not

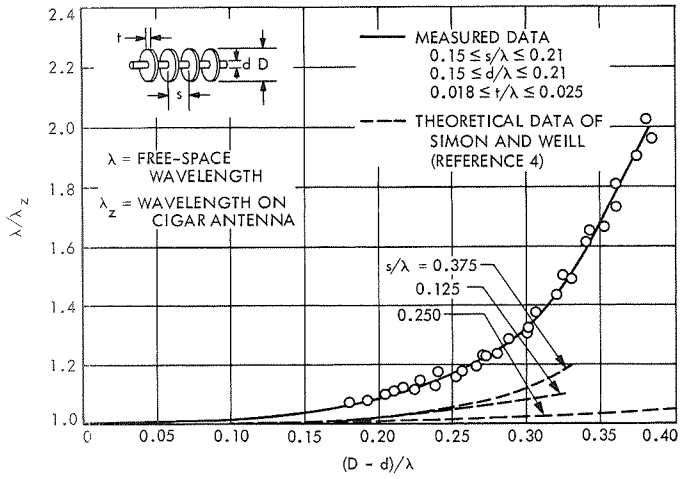

Figure 2. Ratio of free-space wavelength to wavelength on the cigar antenna as a function of normalized disc depth

significantly affect the phase velocity within the parameter limits shown. Significant data could not be taken below $(D - d)/\lambda = 0.18$ because of the measurement problems previously indicated. Certainly, the assumption of the point at zero seems justified, but the curve between there and the first data point must remain suspect.

Cigar Antenna Design

Using the general phase velocity criteria for a low-sidelobe endfire slow-wave antenna of about 22-dB gain (Reference 3), a cigar antenna was designed. Some empirical manipulation of the disc diameter in the constant velocity section where the velocity is near the free-space value was necessary to achieve the best results, indicating that the interpolated region of the phase velocity curve may indeed be in error, although certainly not grossly so.

The final design is shown in Figure 3. The waveguide inside diameter in regions A through E is 3.477 cm; in region I, it is tapered linearly to 8.192 cm. This small flare was found to substantially reduce the wide-angle radiation. The diameter of the center conductor in region A is linearly tapered from a point to 0.635 cm. The diameter in region B is constant at this value. In region C, the diameter tapers linearly to 1.415 cm. Region D is constant at this value, and region E has a diameter of 1.080 cm. The center conductor dimensions were determined empirically such that a low voltage standing-wave ratio would be achieved.

The disc-on-rod structure begins at the right side of region F in Figure 3. With the exception of the taper at the radiating end, it consists entirely of discs of thickness 0.0762 cm, spaced 0.625 cm, on a rod of

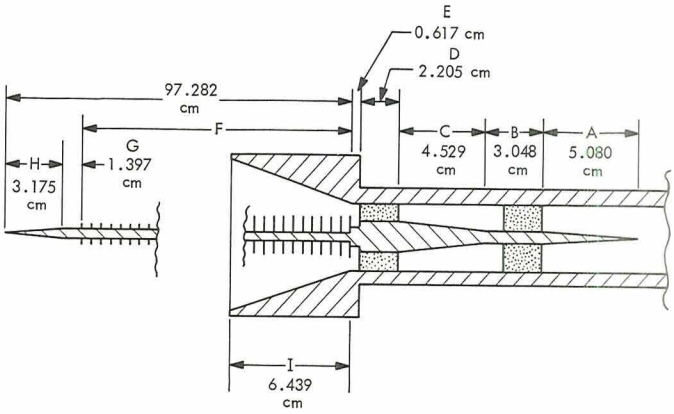

Figure 3. Cigar antenna physical configuration

diameter 0.625 cm. The first disc at the right of region F has a diameter of 1.704 cm. The disc diameter is tapered linearly over a length of 10.160 cm to a diameter of 1.549 cm and over a further distance of 45.72 cm to a diameter of 1.080 cm. This diameter is then held constant over a length of 33.020 cm. The disc diameter is then linearly tapered into the support rod over a distance of 3.810 cm. Region G has the constant diameter of the support rod, and, in region H, the diameter is linearly tapered to a point. The cigar is supported by foam plugs with a dielectric constant of about 1.02.

Experimental Results

The antenna was fed with a linearly polarized TE_{11} mode in the circular waveguide, and radiation pattern and voltage standing-wave ratio measurements were taken. Results were found to be good over the range of 7–9 GHz.

A typical radiation pattern is shown in Figure 4. While only the *H*-plane pattern is shown, the *E* and *H* planes are virtually identical over the main lobe and very similar over the full sphere. In both planes, radiation beyond an angle of 50 deg is more than 40 dB below the peak of the beam, except near 7 GHz, where it is down about 35 dB.

Directivity and beam efficiency were computed by pattern integration over the full sphere. While the directivity of 21.5 dB is significantly less than the 22.5-dB measured gain of an X-band feed horn, it is shown in Figure 5 that, at the edge of the Mars Deep Space Station antenna subreflector (29-deg included angle), the same amount of energy is included in the beam of the cigar as in the beam of the feed horn, and that the beam efficiencies are quite similar over the entire subreflector. This leads to the assumption that, while the beam shapes are different, the antenna efficiency will be essentially the same with either feed.

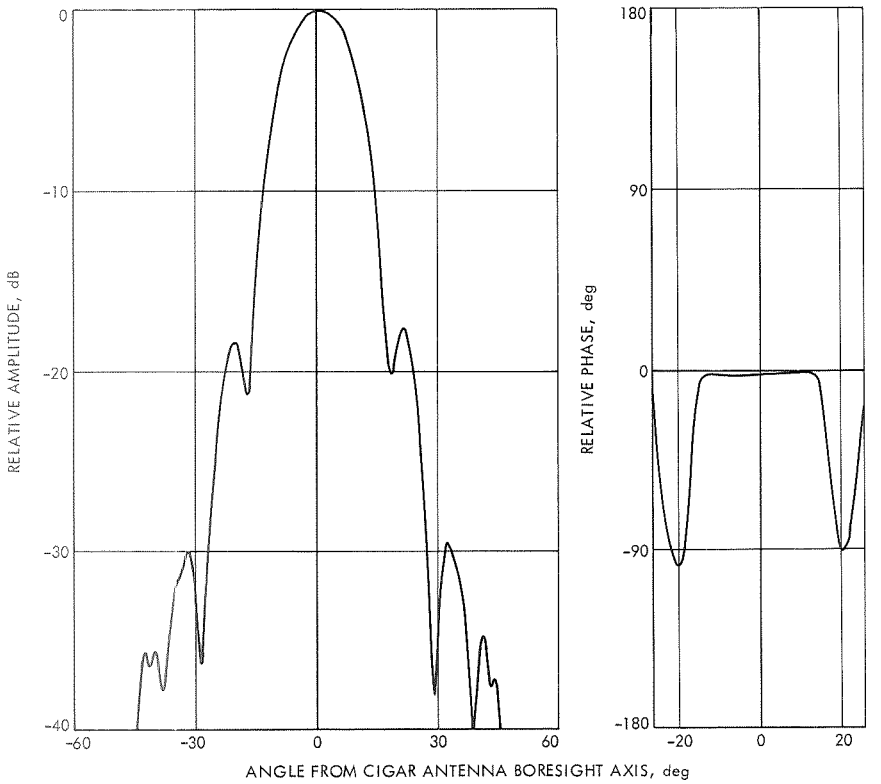

Figure 4. Relative amplitude and relative phase as functions of angle from the cigar antenna boresight axis (typical of both *E* and *H* planes at 8500 MHz)

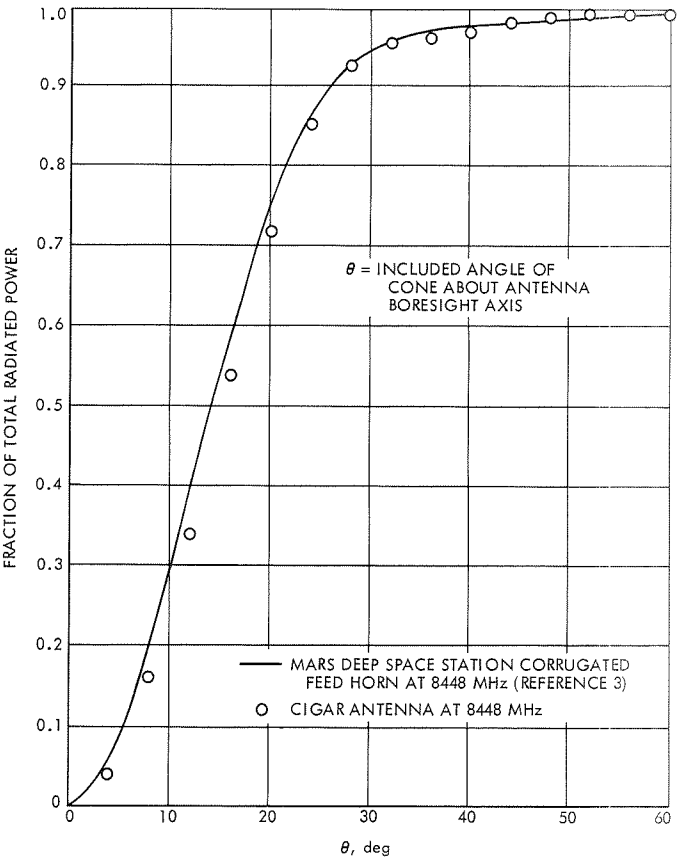

Figure 5. Fraction of the total radiated power contained in a cone about the antenna boresight axis

It must be pointed out that no actual gain measurements have yet been made with the cigar, and nothing is yet known of the possible losses on the disc-on-rod structure. Integration of the X-band horn pattern gave a directivity of 22.5 dB, in good agreement with measurements. This gives confidence in the pattern integration technique, providing the radiator is virtually lossless.

Figure 6 shows the 10-dB bandwidth, phase center location, and voltage standing-wave ratio of the cigar antenna as functions of frequency. Of

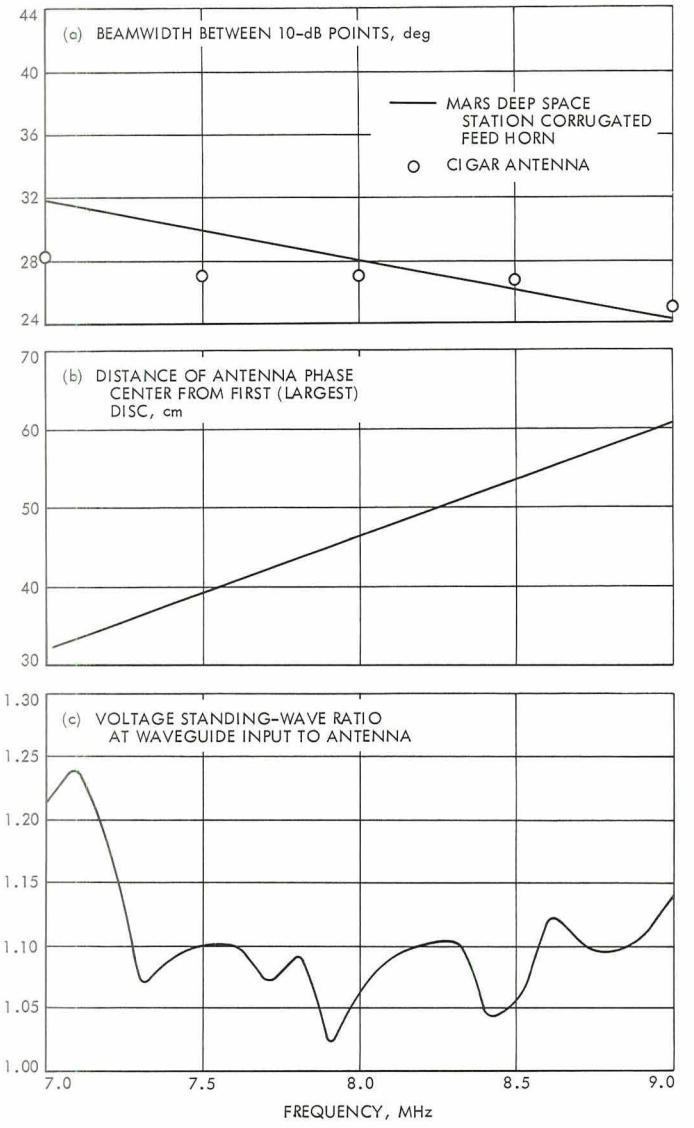

Figure 6. 10-dB beamwidth, phase center location, and voltage standing-wave ratio of cigar antenna as functions of frequency

particular interest is the virtual frequency independence of the beamwidth compared to the usual inverse frequency relationship demonstrated by the curve for the feed horn. Unfortunately, the phase center is not as well-behaved.

Conclusions

The phase velocity curves of Simon and Weill are in error. Using the phase velocity curves generated experimentally, a cigar antenna can be designed with good gain and sidelobe characteristics. If the losses on the disc-on-rod structure are small, the cigar will make a good feed device for cassegrain antennas or a good medium-gain lightweight antenna for other applications.

References

1. Levy, G., Dickinson, R., and Stelzried, C., "S/X Band Experiment," in *Supporting Research and Advanced Development,* Space Programs Summary 37-61, Vol. III, pp. 93–95. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 28, 1970.
2. Brunstein, S. A., "A New Wideband Feed Horn with Equal E and H Plane Beamwidths and Suppressed Sidelobes," in *The Deep Space Network,* Space Programs Summary 37-58, Vol. II, pp. 61–64. Jet Propulsion Laboratory, Pasadena, Calif., July 31, 1969.
3. Jasik, *Antenna Engineering Handbook,* Chap. 16. McGraw-Hill Book Company, Inc., New York, 1961.
4. Simon, J. C., and Weill, G., "A New Type of Endfire Antenna," *Ann. Radioelectricite,* Vol. 8, p. 183, 1953 (in French).